FUTURE STUDIES OF PLANETARY RINGS BY SPACEPROBES*

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and

CONCLUDING REMARKS ON THE PLANETARY RINGS CONFERENCE†

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ABSTRACT

In the past five years ring systems have been discovered around Uranus and Jupiter and a wealth of new data acquired about Saturn's rings. This vigorous observational program has been accompanied by renewed theoretical interest in ring systems. Although all of these topics have been addressed in papers at this first conference on planetary rings, these concluding remarks are focused on some of the key aspects of Saturn's rings about which more needs to be understood through further data analysis, calculations, and observations.

INTRODUCTION

I have chosen to focus these concluding remarks on certain aspects of Saturn's rings, not because the other ring systems are unimportant, but because most is known about Saturn's rings. In addition, we must begin thinking about the critical new measurements which will provide major new infusions of data for the Saturn ring system, while for Jupiter and Uranus we expect major new observations with currently approved missions and with continuing ground based observations.

I have further focused these remarks on six broad properties of Saturn's rings: the macrostructure of the rings on the scale of $\gtrsim 10^3$ km , the microstructure of the rings on smaller scales, the particle size distribution and mass of the rings, the physical thickness of the rings, the composition of the ring particles, and the electromagnetic properties of the rings. For each of these categories I will briefly discuss what we might expect to learn from further analysis of the Voyager data, what theoretical problems appear especially interesting, and what new measurements we might imagine acquiring. The following discussion is necessarily abbreviated and is certainly not a comprehensive review of all the significant observations and ideas discussed at this conference.

MACROSTRUCTURE

The macrostructure of Saturn's rings concerns the organization of the ring system into major regions such as the classical A,B,and C rings. It also includes the apparent subdivision of the B ring into four roughly equivalent radial regions. The basic questions concern the nature of the physical processes which caused and have maintained the structure. As a result, it is important to improve the characterization of the edges of these regions. Voyager data may provide additional information on the exact shape of the edges, the optical depth of the edges as a function of longitude, and the phaseshift of the elliptical figure of the outer edge of the B ring which is due to a satellite resonance. The Voyager data may also yield more information on the similarity of the C ring and the Cassini Division.

From a theoretical standpoint, a key question is the physical process which maintains the inner edges of both the A and the B ring. Associated with these inner edges is a characteristic density decrease and an adjacent, uniform region of low optical depth. Both of these features may be theoretically important. Another open question is the orbital dynamics of satellite 1980S26 which is thought to be absorbing the angular momentum flowing outward from the edge of the A ring. With current theory, it would appear that the absorbed angular momentum cannot be transferred to Mimas because of the lack of an exact resonance and that 1980S26's orbit is still evolving radially.

In the future, a Saturn orbiter could undertake multiple stellar occultations of the rings. As has been graphically illustrated in the case of Uranus' rings, multiple occultations can provide important information on the shape of the edges of the rings and upon their dynamical motion.

MICROSTRUCTURE

The microstructure of the rings includes those features of the rings with scale $\lesssim 10^3$ km . There are a large number of such features in Saturn's rings for which accurate locations can be derived from the Voyager data. While some features have already been classified as density waves or bending waves, most remain unclassified, and may be due to a viscous instability or to other currently unrecognized physical processes. Detailed correlations of the imaging, stellar occultation and radio occultation data will considerably aid in the identification of such processes and permit the classification of additional features. It will also be important to establish the azimuthal properties of the various features in the rings to the extent that Voyager data permit. It should also be possible to refine the analysis of the bending waves and the density waves which have already been identified and to continue the search for imbeded moonlets or material in the various gaps in the rings. There is some preliminary evidence from the photopolarimeter that such material does exist.

On the theoretical side, a number of calculations seem of particular interest. The nature of viscous instability for a realistic particle size distribution certainly seems pertinent and may well permit an understanding of some of the many features in the ring system. Similarly, nonlinear calculations of density waves and bending waves may be very useful in further interpreting the Voyager measurements. It also seems of interest to determine whether the hyperfine splitting of satellite resonances can result in any observed effects in the ring system.

In the future, an orbiting spacecraft can provide a great deal of new information on the microstructure of the rings. Certainly imaging at a much higher resolution and with much more complete azimuthal coverage could be quite important. Similarly, multiple stellar occultations and multiple radio occultations of the rings could also provide significant information on the nature of the many features apparent in the ring system, especially in the thicker B ring which was not as well probed by Voyager.

SIZE DISTRIBUTION and MASS

The radio occultation data contain information on the distribution of particles with radii of a few centimeters and a few meters. Further analysis on a more detailed spatial scale will provide information on the nature and spatial variation of the size distributions. In addition the comparison of the radio occultation data with the stellar occultation and imaging data will further characterize the distribution of particles smaller than one centimeter. Note, however, that because of the very long slant pathlength of the radio occultation experiment the signal was severely attenuated by the B ring. As a result, the B ring, which contains the bulk of the mass of the ring system, will not be well characterized.

Theoretical calculations of the size distribution and mass of the rings are beginning to address specific details of the equilibrium processes which may be occurring in the ring system. It would be particularly interesting to understand theoretically the nature of the apparent upper limits in particles sizes of 4 to 5 meters radius which the radio occultation data indicate are characteristic of the A and C rings. The relative paucity of smaller particles in the optically thin C ring and Cassini Division may also be of physical significance.

In the future, an orbiter which could perform multiple radio occultations, especially with the B ring more open and therefore with smaller slant optical depths, could characterize the distribution of centimeter and meter-sized particles in the B ring. In addition, a ring scattering experiment in which the radio transmissions from the spacecraft scatter obliquely off the rings should allow the direct determination of the nature of the particle size distribution in the centimeter to meter size range. This would complement the occultation data which directly characterize the 1 to 4 centimeter particle sizes and the 1 to 10 meter size particles. High resolution imaging of the rings could possibly provide information on particles of the order of a kilometer or larger which should produce wakes in the ring system. Since there is, unfortunately, very little direct information available for particles in the 10 meter to kilometer size range and it would be particularly interesting to consider approaches which would provide information on the particles in that size range.

As the B ring becomes more open over the next few years, continued use of modern Earth-based systems such as the Very Large Array could provide important information on the opacity of the B ring at the centimeter wave lengths and shorter.

PHYSICAL THICKNESS

The physical thickness of the rings is directly related to the dynamics of the rings and to the particle size distribution. Unfortunately, Voyager had limited capability for directly determining the physical thickness of the rings, although measurements of the physical thickness at the edges of gaps can be refined. Even though it appears that these edge thicknesses are not typical of the bulk of the ring system, they do provide important dynamical information about the formation of those edges.

On the theoretical side, it would appear that calculations involving a distribution of particle sizes could provide important new information on the vertical distribution of particles of different sizes and could help focus the nature of future measurements.

In the future, a Saturn orbiter would provide multiple passes through the ring plane during which high-speed photometry might yield thickness information. In 1994 it should of course be possible to repeat the edge-on viewing measurements of the rings from Earth. However, the definitive measurements may have to wait until it is possible to image the particles from a ring probe or to bounce light pulses off of the ring from an orbiting spacecraft system, recording the reflections with sufficient precision to determine the density distribution of particles in the vertical direction.

COMPOSITION

Although the Voyager data will yield little definitive information on the composition of the ring particles, there is some information in the color differences and phase angle dependence of scattered light and in their comparisons with temperature measurements of the ring material. Most of the composition studies, however, will have to be based on future measurements. For instance, a suitable infrared sensor system for the Space Telescope might provide significant new information on the radial dependence of the composition of material in Saturn's rings. Of course, an infrared spectrometer and imager on a Saturn orbiter could provide such information in even greater detail.

ELECTROMAGNETIC PROPERTIES

The Voyager data contain a wealth of information on the so called "spokes" and significant progress has been made in analyzing some of their characteristics. There is, however, the opportunity for further analysis of the periodicity of the spokes, their azimuthal distribution, and their radial and azimuthal evolution as well as a refined analysis of the optical scattering properties of the spoke particles. Continued studies of the Saturn electrostatic discharges should better characterize their periodicities, their spectral properties, and perhaps with further calibration and modeling, their polarization. A related observation which may yield to further analysis is that of the density of the neutral hydrogen cloud which would provide an indirect indication of the electron density in the region of the rings.

In general the theoretical understanding of the spokes is much less well developed than is that of the other dynamical processes. This is not unexpected, since it has long been known that celestial mechanics are important for the rings, while it has been apparent for only the last two years that electromagnetic properties might be important. As the theory continues to develop, it will be possible to better pose the questions which can be addressed by the Voyager data. Theoretical ideas about the triggering mechanism for spoke formation and about the physical process which controls the longitude and local time distribution of the spokes are of interest as are models of Saturn electrostatic discharges whose association with the rings is being debated.

Future observations with the Space Telescope can provide synoptic coverage of the spokes during periods of different levels of solar activity. This may be relevant since the change in solar activity may affect the plasma environment which in turn may affect the formation and dynamics of the spokes.

With an orbiter it would be possible with better time resolution and imaging to more fully characterize both radial and azimuthal development of the spokes. It would also be possible with an ultraviolet spectrometer to better characterize the nature of the hydrogen ring cloud, while an improved radio astronomy experiment could provide new information on the dispersion, polarization and bandwidth of the electrostatic discharges.

CONCLUSION

Ring systems offer us examples which are rich in the dynamical processes which may be important not only on a planetary scale but also on the scale of the Solar System and galaxies. In the next few years there is much to be learned from the available Saturn data and there should be an infusion of new data and ideas concerning the rings of Uranus and Jupiter. As a result, I would expect that this is just the first of several conferences on planetary rings.